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The Control of Some Soil-Borne Diseases of Plants by Fungicides Applied to the Soil in Fertilizer

By William L. Doran

The methods described for the control of such soil-borne diseases as clubroot of cabbage, smut of onion and damping-off of seedlings should be of special interest and value to growers of vegetables.

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THE CONTROL OF SOME SOIL-BORNE DISEASES OF PLANTS BY FUNGICIDES APPLIED TO THE SOIL IN FERTILIZER

By William L. Doran, Research Professor of Botany

Introduction

It appears from a recent list of some 200 fungicidal materials (16)*, most of them trade-named, that only about seven percent are used for soil treatment. These are, therefore, greatly outnumbered by fungicides, proprietary and others, intended for the treatment of seeds or for the spraying of foliage and fruit.

Among the relatively new organic fungicides, the nature and uses of some of which have been briefly summarized by McCallan (31), are such now well-known materials as Arasan, Fermate, Dithane, Phygon, and Spergon; and some of these have been used, at least experimentally, for the treatment of soil. For example, soil treatment with Arasan was (34) effective against damping-off of cucumber, pepper, spinach, and tomato, although control was more complete when seed and soil treatment with this fungicide were combined. Dithane applied to soil at the rate of 75 pounds per acre gave better control of damping-off of peas than did seed treatment with Spergon (23); and there was marked reduction in the severity of root rots of bean when Dithane D-14 was applied as a soil treatment in the planted row at the time of seeding (29). Wettable Spergon 0.7 gm. per square foot was effective in protecting tomato seedlings against damping-off when applied to soil immediately after transplanting (3).

Fungicides may be applied to soil either dry, as in a dust carrier, or as liquids, in solution or suspension. In the case of a very light application of a soil fungicide, too light perhaps to be distributed evenly and easily unless in some carrier, certain fungicides, as will be shown, may be conveniently, safely, and effectively applied to soil in commercial fertilizer used as a carrier.

The possibility of such combinations of fungicides and fertilizer has been suggested before (30, 6, 7, 10, 11). Onion smut was controlled by Fermate 58 pounds in fertilizer 1500 pounds per acre (13). Dithane 75 pounds mixed with 800 pounds of a 5-10-5 fertilizer per acre controlled damping-off of peas and was no less safe and effective than Dithane used alone (29). More recently Hildebrand and coworkers (24) controlled blackroot of sugar beet seedlings using Arasan three or four pounds per acre in fertilizer 300 to 400 pounds per acre, applying it in the row and above the seeds. They found that Arasan thus used retained its fungicidal power for as long as fourteen months after being mixed with the fertilizer.

The writer applied fungicides to the soil for the control of clubroot of cabbage (*Brassica oleracea* L. var. *capitata* L.), caused by *Plasmodiophora brassicae* Wor.; smut of onion (*Allium Cepa* L.), caused by *Urocystis cepulae* Frost; and damping-off, caused by *Pythium* spp., of seedlings of cabbage, onion, beet (*Beta vulgaris* L.), chard (*Beta vulgaris* L. var. *Cicla* L.), spinach (*Spinacea oleracea* L.), cauliflower (*Brassica oleracea* L. var. *botrytis* L.), cucumber (*Cucumis sativus* L.), cress (*Lepidium sativum* L.), lettuce (*Lactuca sativa* L.), endive (*Cichorium Endiva* L.), tomato (*Lycopersicon esculentum* Mill.) eggplant (*Solanum Melongena* L.) and pepper (*Capsicum frutescens* L. var. *grossum* (L.) Bailey).

The following fungicides, hereafter referred to by their trade names, were among those used in this work or are mentioned below. For names of the manufacturers, the reader is referred to the recent publication of Frear, Hilborn and Prince (16).

*Numbers in parenthesis refer to Literature Cited, pp. 26-28.

Arasan, 50 percent tetramethyl thiuram disulfide
Dithane D-14, 25 percent disodium ethylene bisdithiocarbamate hexahydrate
Dithane Z-78, 65 percent zinc ethylene bisdithiocarbamate
Dow 9, 100 percent zinc, 2, 4, 5-trichlorophenate
Dow 9-B, 50 percent zinc, 2, 4, 5-trichlorophenate
Elgetol, sodium dinitro-ortho-cresolate
Fermate, 70 percent ferric dimethyl dithiocarbamate
Guantal, diphenyl guanidine phthalate
Hyamine 10-X, di-isobutyl oloxy ethoxy ethyl dimethyl benzyl ammonium chloride
MTD, morpholine thiuramdisulfide
Permaseptic, 3 percent phenyl mercury acetate
Phygon-XL, 2, 3-dichloro-1, 4-naphthoquinone
Puratized Agricultural Spray, 5 percent phenyl mercuri triethanol ammonium lactate
Semesan Bel, 12 percent hydroxymercurinitrophenol, 3.2 percent hydroxymercurichlorophenol
Spergon, tetrachloro-parabenzoquinone
Tuads, tetramethyl thiuram disulfide
Zerlate, 76 percent zinc dimethyldithiocarbamate

Methods

Except as otherwise indicated below, the work here described was done in a greenhouse, the soil usually in flats, shallow boxes, about four inches in depth. Naturally infested soil was used in the work on onion smut; field soils were inoculated with diseased and decayed cabbage roots or with naturally infested soil in the work on clubroot; and in that work and in the work on damping-off three parts sifted loam, naturally infested, mixed with one part sand were used.

Unless otherwise indicated, fungicides, usually in fertilizer, were thoroughly mixed with the soil immediately before or less than one day before seeding. All rates of applications are expressed in grams or cubic centimeters per square foot of soil surface. One gram per square foot is equal to about 0.6 pound or 9.6 ounces per square rod, about 96 pounds per acre. In the few cases in which fungicides were applied in solution or suspension, one quart was used per square foot. All flats, with or without fungicides, were watered alike.

All fungicides, unless otherwise indicated, were applied in a 5-8-7 fertilizer, used at the rate of 16.0 gm. per square foot. Hydrated lime, 20 gm. or more per square foot, was used in some instances. If fertilizer was used as a carrier for the fungicide, soil without fungicide received the same application of fertilizer. If the fungicide used was a liquid, the fertilizer with the fungicide added to it was allowed to dry and was then ground before being used.

Seeds were sowed in equal numbers, 100 to 400 in each lot.

In comparing fungicides, results are based on the percentage of plants which became infected with onion smut or cabbage clubroot, on growth as measured by green weight, and on the relative number of plants which lived; i.e., escaped damping-off or other disease. The bases of comparison are the numbers which lived in untreated soil. Thus if the relative number of seedlings which lived in untreated soil is given a value of 100 and the relative number which lived in treated soil is 117, this simply means that 17 percent more seedlings survived in the treated than in the untreated soil. Similarly, if the average green weight per plant in untreated soil is given a value of 100 and the green weight per plant in a treated soil is expressed as 88, this is equivalent to saying that the plants in the treated soil weighed 12 percent less than those in the untreated soil.

The Control of Clubroot and Damping-off of Cabbage by Fungicides Applied to the Soil

Mercury salts were in all cases applied to the soil in fertilizer. The effects of mercurous chloride, mercuric chloride, hydrated lime, and sodium chloride on the percentage of cabbage plants infected with clubroot, the number of plants which lived, and the average weight of the plants are recorded in Table 1. In this and other tables, each series represents a separate experiment, the results of which are brought together in one table, with others of a similar nature, in order to save space.

As in the days of Halsted (22), clubroot was not controlled by sodium chloride. The disease was as general (see Series A and B) in soil to which sodium chloride 10.0 gm. per square foot was applied as it was in untreated soil.

TABLE 1.—EFFECTS OF SOIL TREATMENTS WITH MERCUROUS CHLORIDE AND MERCURIC CHLORIDE, WITH AND WITHOUT HYDRATED LIME OR SODIUM CHLORIDE, ON CLUBROOT OF CABBAGE, AND STANDS AND WEIGHTS OF PLANTS.

Soil Treatments per Square Foot	Percentage of Plants Infected with Clubroot	Relative Number of Plants which Lived	Average Green Weight per Plant Expressed As Relative Numbers
SERIES A			
None	95	100	100
Sodium chloride			
10.0 gm. alone	100	114	83
Mercurous chloride			
0.15 gm. alone	33	121	107
0.15 gm. and sodium chloride 10.0 gm.	11	132	122
0.2 gm. alone	20	142	99
SERIES B			
None	100	100	100
Sodium chloride			
10.0 gm. alone	100	55	103
Mercurous chloride			
0.1 gm. alone	72	153	126
0.1 gm. and sodium chloride 10.0 gm.	37	136	183
0.15 gm. alone	57	144	194
0.15 gm. and sodium chloride 10.0 gm.	25	96	169
0.2 gm. alone	28	104	184
0.2 gm. and sodium chloride 10.0 gm.	16	95	165
SERIES C			
None	100		100
Hydrated lime			
20.0 gm. alone	10		136
Mercurous chloride			
0.2 gm. alone	54		96
0.2 gm. and hydrated lime 20.0 gm.	0		122
0.2 gm. and sodium chloride 10.0 gm.	50		94
SERIES D			
None	100	100	100
Hydrated lime			
25 gm. alone	26	100	100
35 gm. alone	19	100	100
Mercuric chloride			
0.3 gm. and hydrated lime 25 gm.	10	125	76
0.3 gm. and hydrated lime 35 gm.	0	125	128
0.35 gm. and hydrated lime 25 gm.	0	117	72
0.35 gm. and hydrated lime 35 gm.	0	117	132
Mercurous chloride			
0.3 gm. and hydrated lime 25 gm.	12	106	114
0.3 gm. and hydrated lime 35 gm.	9	143	125
0.35 gm. and hydrated lime 25 gm.	0	99	105
0.35 gm. and hydrated lime 35 gm.	0	128	125

According to Booer (4), sodium chloride added to soil causes an increase in the concentration of mercury produced by the decomposition of mercurous chloride in soil. Perhaps because of this effect, there was less clubroot (see Series B) when mercurous chloride 0.1, 0.15, or 0.2 gm. per square foot was used with sodium chloride than when mercurous chloride in these amounts was used alone. Similarly, in the experiment represented by Series A, there was 33 percent clubroot when mercurous chloride 0.15 gm. per square foot was used alone; 11 percent clubroot when this application of mercurous chloride was accompanied by an application of sodium chloride 10.0 gm. Mercurous chloride 0.2 gm., with or without sodium chloride, gave poor results (Series C), 50 or 54 percent of the plants being infected with clubroot as compared with 100 percent infected plants in untreated infested soil.

Sodium chloride 10 gm. per square foot, used alone, was either without effect on growth, as in Series C, or possibly injurious, as in Series A. But when there was some degree of control of clubroot, as in Series A and B, plants made better growth with mercurous chloride and sodium chloride both applied to the soil than in untreated soil. Even so, this combination of mercurous chloride and sodium chloride used together did not give satisfactory control of clubroot.

Mercurous chloride 0.10, 0.15, or 0.20 gm. per square foot, used alone, lessened the percentages of plants with clubroot (see Series A, B, and C) but failed to control the disease satisfactorily.

Clubroot of cabbage, with 100 percent of the plants infected in the untreated soils, was entirely prevented (see Series C) by mercurous chloride 0.2 gm. used with hydrated lime 20 gm. per square foot, and (see Series D) by mercurous chloride 0.35 gm. used with hydrated lime 25 or 35 gm. per square foot. In the work represented by Series C, there was 100 percent clubroot in untreated soil, 54 percent with mercurous chloride, 10 percent with hydrated lime, and no disease with mercurous chloride and hydrated lime used together.

In the experiment summarized in Series D, there was 100 percent clubroot in untreated soil, 26 or 19 percent with hydrated lime 25 or 35 gm. per square foot, and less clubroot or none at all when soil was treated with hydrated lime and mercurous chloride as above stated or with hydrated lime and mercuric chloride 0.3 or 0.35 gm. per square foot. However, when hydrated lime was applied at the rate of 25 gm. per square foot, the plants grew less well, weighed less, in soil treated with mercuric chloride than in soil treated with mercurous chloride; but when the application of hydrated lime was increased to 35 gm. per square foot, there was good growth of cabbage plants, weighed 120 days after seeding, with either mercuric chloride or mercurous chloride.

These mercury salts, used with or without lime (see Series A, B, D), did not interfere with the germination of the seeds of cabbage. The number of plants which lived was greater by 43 percent (Series D) in soil which received mercurous chloride 0.3 gm. and hydrated lime 35 gm. per square foot than in untreated soil.

The percentage of plants with clubroot was much reduced (see Series C and D) by hydrated lime 20, 25, or 35 gm. per square foot, used alone; but only when mercurous or mercuric chloride was used in conjunction with hydrated lime, was control complete. The possible relation or lack of relation of soil pH values to clubroot of cabbage is further considered below; but it should be noted here that the soil used in Series C had a pH value of 7.8 seven weeks after treatment with hydrated lime, while the pH value of this soil without treatment was 6.3. Sixty days after seeding, the soil used in Series D had a pH value of 7.8 with hydrated lime, 5.7 without such treatment.

In Table 1 are listed the percentages of cabbage plants which became infected with clubroot. Table 2 lists not only the total percentages of plants which be-

TABLE 2.—EFFECTS OF MERCUROUS CHLORIDE AND MERCURIC CHLORIDE, WITH AND WITHOUT HYDRATED LIME, SULFUR, OR SODIUM CHLORIDE, ON STANDS AND GROWTH OF CABBAGE PLANTS AND ON SEVERITY OF CLUBROOT.

Soil Treatment per Square Foot	Percentage of Plants Infected with Clubroot					Relative Number of Plants Which Lived	Average Green Weight per Plant Expressed as Relative Numbers
	Trace	Slight	Moderate	Severe	Total		
None				100	100	100	100
Hydrated lime 20 gm		13	43	44	100	135	149
*Sulfur 4.2 gm				100	100	88	74
Mercurous chloride 0.2 gm. alone		8	9	83	100	100	196
with hydrated lime 20 gm		13			13	100	228
with sulfur 4.2 gm				100	100	82	81
with sodium chloride 15 gm.	22	17	22		61	61	172
Mercuric chloride 0.1 gm. alone				100	100	107	129
with hydrated lime 20 gm	18		9	45	72	104	217
with sulfur 4.2 gm				100	100	85	89
with sodium chloride 15 gm.		19	28	53	100	112	143

* The sulfur used in the experiment was the National Sulfur Company's Crown Brand.

came infected with clubroot, but also the percentages which became severely, moderately or only slightly infected with the disease in soil variously treated.

Soil pH values 28 days after seeding were as follows: with sulfur 4.2 gm. per square foot, 5.5; in untreated soil, 5.75; with hydrated lime 20 gm. per square foot, 6.85.

Growth was apparently retarded by this application of sulfur whether used alone or with mercurous or mercuric chloride. Sulfur used alone did not lessen the severity of clubroot, and there was no control of the disease when sulfur was used with mercurous chloride 0.2 gm. or mercuric chloride 0.1 gm. per square foot.

Clubroot was slightly less severe when mercurous chloride 0.2 gm. or mercuric chloride 0.1 gm. was used with sodium chloride 15 gm. per square foot than when either was used alone. But neither alone nor with sodium chloride did these mercury salts control clubroot.

Hydrated lime 20 gm. per square foot reduced the number of severely infected plants to 44 percent, but did not reduce the total percentage of plants with clubroot.

There was 100 percent clubroot in soil with mercurous chloride 0.2 gm. or mercuric chloride 0.1 gm. used alone. But the percentage of plants severely infected was a little less and (probably for this reason) the plants made better growth with mercurous chloride than with mercuric chloride.

The best control of clubroot, only 13 percent of the plants infected and they only slightly, was given by mercurous chloride 0.2 gm. and hydrated lime 20 gm. used together. Mercuric chloride 0.1 gm. similarly used with hydrated lime was much less effective, there being a total of 72 percent clubroot, 45 percent severe infection, in soil so treated.

Some of these results are also evident in Figures 1 – 4. These show plants grown in untreated soil (Fig. 1), with 100 percent severe infection; in soil treated with hydrated lime 20 gm. per square foot (Fig. 2); in soil treated with mercurous chloride 0.2 gm. per square foot (Fig. 3); and in soil which received both hydrated

lime 20 gm. and mercurous chloride 0.2 gm. (Fig. 4), with only 13 percent clubroot, classified as slight. When the plants shown in Figure 4 are compared with those in Figure 1, the good control of clubroot as well as the superior growth of plants resulting from the combined action of hydrated lime and mercurous chloride is easily seen.

To determine the effect of soil moisture on the control of clubroot of cabbage by mercurous chloride and hydrated lime, soil was first dried, then inoculated and watered and thereafter kept watered to 80, 65, or 50 percent of its water-holding capacity. Hydrated lime was used in all cases at the rate of 20 gm. per square foot. Results are recorded in Table 3.

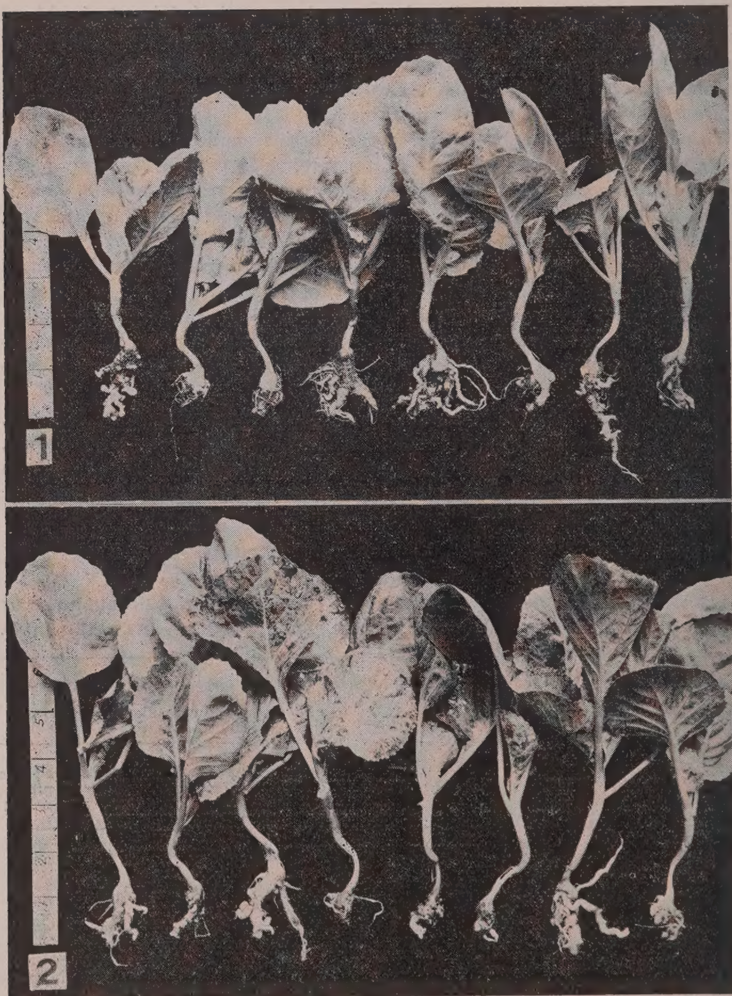
With hydrated lime only, no mercurous chloride applied, the percentage of plants with clubroot was 78.1, none of it severe, at 50 percent saturation; 86.2 percent clubroot, 37.9 percent severe, at 65 percent saturation; and 100 percent infection, all severe, at 80 percent saturation. In the most nearly saturated soil, therefore, hydrated lime gave no protection against the disease.

The degree of control of clubroot obtained by mercurous chloride and hydrated lime was considerably affected by the moisture content of the soil, the disease being more readily controllable in the soils at 50 or 65 percent saturation than in the soil which was kept watered to 80 percent saturation. Under all three moisture conditions, control was somewhat better with 0.3 gm. of mercurous chloride than with 0.2 or 0.25 gm.

To determine the effects of the several factors involved on the growth of plants, some plants were removed and weighed at various time intervals after seeding, as shown in Table 3. Here, as elsewhere in this work, growth may have been improved by some degree of control of the disease or may have been retarded by some chemical ill effect of the fungicide on the host plant.

TABLE 3.—EFFECTS OF SOIL MOISTURE ON THE CONTROL OF CLUBROOT OF CABBAGE BY MERCUROUS CHLORIDE IN SOIL TREATED WITH HYDRATED LIME.

Mercurous Chloride (Grams per Square Foot)	Percentage of Plants Infected with Clubroot				Percentage Gain (+) or Loss (−) in Green Weight per Plant as Compared with Plants Grown without Mercurous Chloride			
	Light	Moderate	Severe	Total	14 Days after Seeding	22 Days after Seeding	37 Days after Seeding	52 Days after Seeding
Soil Kept Watered to 50 percent Saturation								
None	56.2	21.9		78.1				
0.15	13.3	3.4		16.7	Unaffected	−3	−21	+35
.2	3.1	3.1		6.2	"	−24	−6	+14
.25	3.3			3.3	"	−16	+12	+29
.3				0.0	"	−21	+26	+41
Soil Kept Watered to 65 percent Saturation								
None	27.6	20.7	37.9	86.2				
0.15	24.1	3.4		27.5	−10	+22	+23	+28
.2	13.8	3.8		17.6	−24	+15	+16	+49
.25	11.1	11.1		22.2	−19	+29	+29	+32
.3	7.4			7.4	−10	+3	+14	+33
Soil Kept Watered to 80 percent Saturation								
None			100.0	100.0				
0.2	16.3	16.3		32.6	−20	−20	+8	+105
.25	8.0	12.0		20.0	−19	+3	+22	+101
.3	12.5	3.8		16.3	−20	Unaffected	+31	+150



Cabbage Plants Grown in Clubroot-Infested Soil.

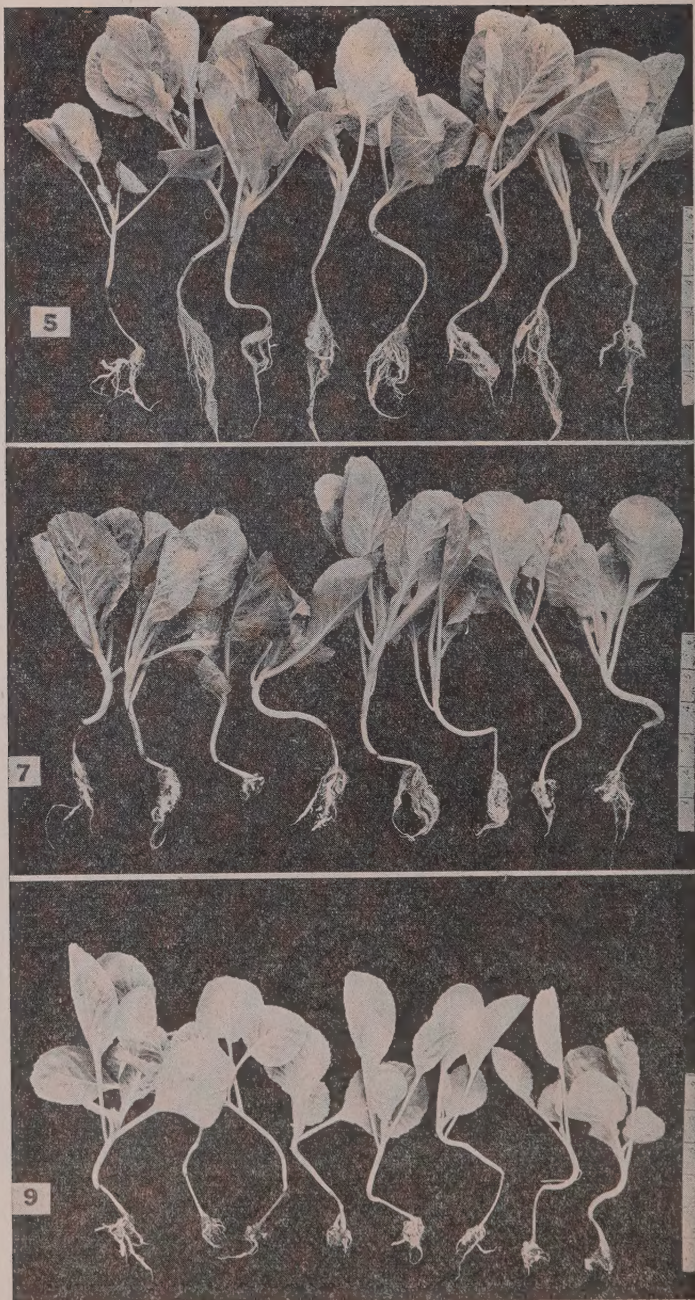
Figure 1. Soil untreated.

Figure 2. Soil treated with hydrated lime 20 grams per square foot.

Cabbage Plants Grown in Clubroot-Infested Soil.

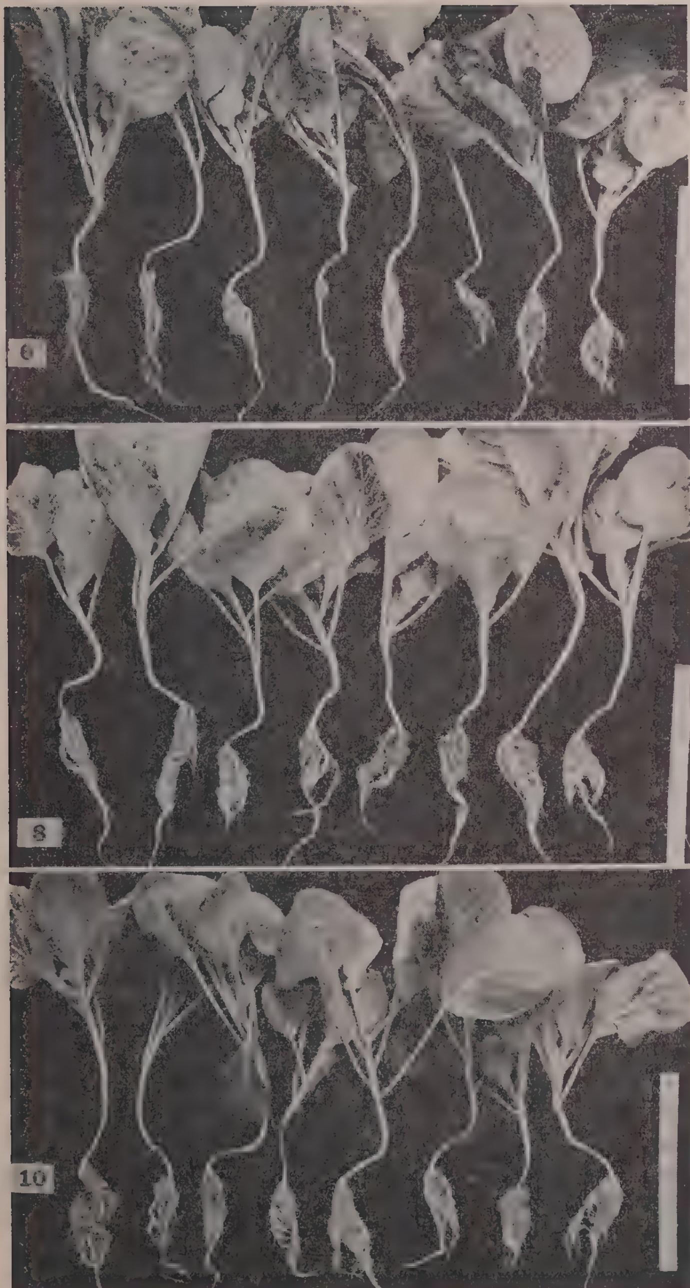
Figure 3. Soil treated with mercurous chloride 0.2 gram per square foot.

Figure 4. Soil treated with hydrated lime 20 grams and mercurous chloride 0.2 gram per square foot.



Cabbage Plants Grown in Clubroot-Infested Soil, treated with hydrated lime 20 grams per square foot.

Figure 5. Soil at 50 percent saturation.
Figure 7. Soil at 65 percent saturation.
Figure 9. Soil at 80 percent saturation.



Cabbage Plants Grown in Clubroot-Infested Soil, treated with hydrated lime 20 grams and mercurous chloride 0.3 gram per square foot.

Figure 6. Soil at 50 percent saturation.
Figure 8. Soil at 65 percent saturation.
Figure 10. Soil at 80 percent saturation.

In the driest soil, growth of seedlings was apparently retarded for 22 days after seeding by all applications of mercurous chloride. In the soil at 65 and 80 percent saturation, growth was retarded by mercurous chloride for 14 days but not for 22 days or more after seeding.

Later, 37 or 56 days after seeding, either because possible ill effects of mercury on the plants had disappeared or because of less clubroot in treated soil, plants in soil which had received applications of mercurous chloride grew better than did plants in soil without such treatment. Differences were greatest in the soil watered to 80 percent saturation, the soil in which there was most clubroot. In this soil, plants which had received the protection against clubroot which mercurous chloride affords weighed, 56 days after seeding, at least 100 percent more than did plants in similar soil which had been treated with hydrated lime alone.

With hydrated lime but no mercurous chloride, the increasing severity of clubroot which resulted from an increasing soil moisture content may be seen by comparing the roots of plants shown in Figure 5, soil 50 percent saturated; Figure 7, soil 65 percent saturated; and Figure 9, soil 80 percent saturated. Lime alone was quite ineffective in controlling the disease in this wettest soil.

The degree of control of clubroot afforded by the addition of mercurous chloride 0.3 gm. to such soil is shown in Figures 6, 8 and 10. The greatest contrast was between roots of plants in Figures 9 and 10, for when this soil was kept at 80 percent saturation, the disease was most severe without mercurous chloride; while with mercurous chloride 0.3 gm. there was only 16.3 percent clubroot and none of it severe.

It is known that clubroot is more severe in soils with high moisture content, but Wellman (42) found that soil moisture content does not have to remain high more than 18 hours to allow infection to take place. In the experiment summarized in Table 3, soil was watered to 80 percent saturation daily. But even in this most nearly saturated soil, the combination treatment of hydrated lime 20 gm. and mercurous chloride 0.3 gm. gave good control of clubroot.

It appears, therefore, that, under the conditions described, clubroot of cabbage as it occurs in seedbeds is controllable by mercurous chloride and hydrated lime used together, usually less well or sometimes not at all by either used alone.

But either, used alone under conditions reported by some investigators, has reduced the severity of the disease. Commercial control of clubroot was obtained by the use of hydrated lime at the rate of 1500 pounds per acre in seedbeds or two tons per acre in the field (42). Applications of hydrated lime which raise the pH value of soil to 7.1 and higher reduced the severity of infection in a greenhouse but did not control the disease in the field (28). Gries et al. (21) found that, at a given calcium–potassium ratio, clubroot followed the expected relation to pH and concluded that one of the effects of pH is probably to alter the concentration of the Ca ion in the soil. Wellman (42) found that clubroot-infested soils ranged in pH values from 5.0 to 7.8 and concluded that the pH value of the soil is not a limiting factor in controlling the disease. This is a conclusion with which Karling (27), after an extensive review of the literature, agreed.

Clubroot has been controlled by mercurous chloride applied in water around individual plants as they were set in the field (36). Thus used, mercuric chloride controlled clubroot better than did mercurous chloride, but the control obtained was incomplete and the investigators (41) regarded the maintenance of a neutral soil reaction by liming as more important. Clubroot was also controlled by mercurous chloride applied to soil immediately before seeding, and treatment with mercurous chloride was considered to be more beneficial than treatment with either mercuric chloride or lime (19).

These somewhat inconsistent results obtained by earlier workers are not surprizing. Mercury compounds could conceivably give better control of clubroot in some soils than in others. And perhaps seasonal differences are factors. Potato scab has been controlled in some years, not in others, with mercurous chloride 5 or 10 pounds per acre (17).

In the work of the writer, soil was treated with mercurous chloride and hydrated lime but once, not in repeated years. Hence it is not known whether repeated treatments would be safe, but such evidence as is at hand does not indicate that it would be unsafe. It has been figured by Booer (4) that an average crop of cabbage (10,000 to 20,000 plants per acre as usually grown) would remove from the soil no more than 0.4 gm. mercury per acre and the same investigator states that mercury is not a cumulative poison. It appears, he states, that mercuric chloride added to soil is there converted to mercurous chloride. According to another investigator (8), mercury compounds are reduced in soil to metallic mercury which then moves as a vapor and it has been shown (44) that such vapors escape from the soil.

A number of other substances, not salts of mercury, were applied in fertilizer to soil infested or uninfested with clubroot and the results with some of the more beneficial are shown in Table 4. Clubroot-infested soil was used in Series A through G; soil not infested in Series H through L.

Clubroot of cabbage was not controlled or was not well controlled by 8-quinolinol 1.5 gm. per square foot; 2, 4, 6-trichlorphenol 1.25 gm.; α-naphthol 3.5 gm.; zinc mercaptobenzothiazole 0.45 gm.; Guantal 0.45 gm.; or calcium cyanamide 10 gm., the last named applied to soil without other fertilizer seven days before seeding. Uramon 8 gm., applied without other fertilizer to limed soil eight days before seeding, decreased the number of plants with clubroot to 24 percent, with 95 percent infected plants in untreated soil. As compared with the results given by mercurous chloride and hydrated lime, that is not very good control.

There was injury to seeds or seedlings of cabbage by potassium dichromate 4.0 gm., ammonium nitrite 4.0 gm., calcium nitrite 4.0. gm, sodium nitrite 4.0 gm., salicylic acid 7.0 gm.; Dow Seed Protectant No. 9B 0.75 gm.; Elgetol 2.0 cc.; Guantal 1.0 gm.; Hyamine 10-X 4.0 gm.; or Spergon 0.7 gm. per square foot.

As has been reported earlier (11), clubroot of cabbage has been controlled by Tuads 0.55 gm. per square foot. But, as shown in Table 4, clubroot was not well controlled by this application of Tuads when the disease was very severe, 100 percent infection in untreated soil. Still, as is evident in Series C, Tuads so used gave better control of clubroot than did Dithane D-14, 2.5 cc. or Phygon 0.4 gm.

With clubroot severe in the check, Fermate 0.7 gm. reduced the severity of the disease but little (see Series B), and that was true also of Arasan 0.7 gm. and Phygon 0.7 gm.

The number of cabbage seedlings which lived was increased least by Fermate 0.6 or 0.7 gm. or Dithane D-14, 2.5 cc.; and most by Tuads 0.55 to 0.7 gm., Phygon 0.4 to 0.7 gm., or Arasan 0.7 to 1.0 gm. per square foot.

Green weight of cabbage seedlings was usually increased by these treatments: least by Fermate 0.6 or 0.7 gm. and by Dithane D-14, 2.5 cc.; and usually most by Tuads 0.55 to 0.7 gm.; also by Phygon 0.45 to 0.7 gm. and by Arasan 0.6 to 1.0 gm.

In the absence of clubroot, stands of cabbage seedlings may be increased, and often with benefit to growth, by Arasan, Phygon, or Tuads; but none of these materials was so effective as mercurous chloride and hydrated lime in protecting cabbage seedlings from clubroot.

TABLE 4.—EFFECTS OF SOME ORGANIC FUNGICIDES ON CLUBROOT, STANDS AND GROWTH OF CABBAGE.

Soil Treatment per Square Foot	Percentage of Plants Infected with Clubroot	Relative Number of Plants Which Lived	Average Green Weight per Plant Expressed as Relative Numbers
SERIES A			
None	30	100	100
Phygon 0.55 gm.	0	300	193
Tuads 0.55 gm.	0	347	245
SERIES B			
None	100	100	100
Fermate 0.7 gm.	67	118	111
SERIES C			
None	68	100	100
Dithane D-14, 2.5 cc.	53	110	114
Phygon 0.4 gm.	50	229	216
Tuads 0.55 gm.	16	333	272
SERIES D			
None	100	100	100
Arasan 0.7 gm.	52	141	178
SERIES E			
None	100	100	100
Tuads 0.5 gm.	32	131	160
SERIES F			
None	100	100	100
Tuads 0.5 gm.	20	237	290
SERIES G			
None	100	100	100
Arasan 0.7 gm.	70	141	178
Phygon 0.7 gm.	62	147	100
SERIES H			
None		100	100
Arasan 0.7 gm.		120	124
Fermate 0.7 gm.		117	111
SERIES I			
None		100	
Phygon 0.6 gm.		330	
Tuads 0.6 gm.		377	
SERIES J			
None		100	100
Arasan 1.0 gm.		233	130
Phygon 0.7 gm.		276	119
Tuads 0.7 gm.		337	114
SERIES K			
None		100	100
Phygon 0.65 gm.		434	186
Tuads 0.65 gm.		589	150
SERIES L			
None		100	100
Arasan 0.6 gm.		134	100
Fermate 0.6 gm.		116	112
Phygon 0.6 gm.		127	100
Tuads 0.6 gm.		134	104

The Control of Smut and Damping-off of Onion Seedlings by Fungicides Applied to Soil or to Seeds

In the work with onion smut, soils known to be infested with *Urocystis cepulae* Frost were treated with fungicides which, unless otherwise indicated, were applied in fertilizer before seeding. In untreated soil, 25.6 to 88.0 percent of the seedlings were infected with smut. Table 5 records the varying degrees of control given by the fungicides.

Sodium nitrite is known to be highly toxic to soil organisms. An application of 4 to 8 ounces per square yard was effective in controlling damping-off of lettuce caused by Rhizoctonia when applied to soil four weeks before seeding (14). Although stands of plants were slightly reduced by the highest rate, it gave better control of the disease than did formaldehyde or chlorpicrin. Other investigators

(15) obtained good control of root-knot nematode and observed good growth of tomato plants when plantings were made as early as one week after soil treatment with sodium nitrite 6 to 12 ounces per square yard, the exact rate of application varying with the type of soil. Calcium nitrite and potassium nitrite have given promising results in controlling tobacco parasites (5).

Since sodium nitrite rapidly changes to the nitrate (15), the interval between soil treatment and seeding or use of the soil may be a factor influencing the effects of treatment on both fungus and host plant. As used by the writer, the nitrites of calcium, sodium or potassium, 3.25 gm. per square foot, failed to control onion smut when applied eight weeks before seeding, the soil having had an opportunity to become reinfested with the fungus meanwhile; and sodium nitrite 3.25 gm. caused some injury to onion seedlings when applied to soil immediately before seeding.

But sodium nitrite 2.75 gm. per square foot, applied to soil three days before seeding, or calcium or potassium nitrite 3.0 gm. per square foot, applied to soil ten days before seeding, gave excellent control of smut (see Series A), there being

TABLE 5.—EFFECTS OF SOME SOIL TREATMENTS ON ONION SMUT AND ON THE NUMBER OF ONION SEEDLINGS WHICH LIVED.

Soil Treatment per Square Foot	Number of Days Between Soil Treatment and Seeding	Percentage of Seedlings with Smut	Percentage of Plants Which Lived
SERIES A			
None		88.0	9.0
Sodium nitrite 2.75 gm.	3	1.5	47.7
Calcium nitrite 3.00 gm.	10	4.5	69.0
Potassium nitrite 3.00 gm.	10	5.3	75.5
SERIES B			
None		69.0	38.0
Potassium dichromate 0.4 gm.	2	45.7	47.7
Potassium dichromate 0.5 gm.	2	11.2	30.2
SERIES C			
None		55.2	22.7
Uramon 8.0 gm.	60	21.4	44.0
SERIES D			
None		49.6	30.0
Fermate 0.4 gm.	1	9.4	42.2
Fermate 0.5 gm.	1	5.6	67.0
Fermate 0.6 gm.	1	1.7	65.7
Fermate 0.7 gm.	1	1.0	64.5
SERIES E			
None		69.0	38.0
Fermate 0.75 gm.	2	0.0	78.3
Fermate 1.0 gm.	2	0.0	77.4
SERIES F			
None		31.5	37.0
Fermate 0.6 gm.	10	5.5	52.6
Fermate 0.7 gm.	10	0.9	78.3
SERIES G			
None		25.6	37.5
Arasan 0.5 gm.	1	0.6	79.5
Arasan 0.6 gm.	1	1.3	76.2
SERIES H			
None		39.0	15.5
Phygon 0.6 gm.	1	0.0	69.0
SERIES I			
None		53.0	13.7
Phygon 0.65 gm.	1	0.0	43.2
Tuads 0.65 gm.	1	0.0	43.2
SERIES J			
None		50.0	18.0
Arasan 0.6 gm.	2	0.0	63.1
Tuads 0.6 gm.	2	0.0	64.6
Phygon 0.6 gm.	2	0.0	70.0

88 percent infected seedlings in untreated soil, 1.5 to 5.3 percent in this soil treated with one of the nitrites.

Potassium dichromate 0.4 gm. per square foot, applied to soil two days before seeding, failed (see Series B) to control smut. Potassium dichromate 0.5 gm. similarly used markedly reduced the percentage of plants infected with smut, but at this rate of application the growth of onion seedlings was slightly retarded.

Urea (Uramcn) has been used as a soil fungicide. When this material was applied to soil as side dressings three to six weeks after sowing seeds of larkspur, a total of 712.5 pounds Uramon per acre, there was a large increase in the number of plants (33) which escaped attack by *Sclerotium rolfsii* Sacc.

Urea (Uramon, containing 42 percent nitrogen) was used in soils to which hydrated lime 20 gm. per square foot had been applied previously. Uramon 4.0 or 6.0 gm. per square foot failed to control onion smut. Used at the rate of 8.0 gm. per square foot and applied to soil 30 or 44 days before seeding, Uramon gave good control of smut but interfered with the germination of the seeds of onion. Uramon 8 gm. per square foot applied to soil 60 days before seeding was not injurious to plants and did lessen the severity of smut (see Series C), but not enough; not nearly so much as did some other materials listed in that table.

Calcium cyanamide, like urea, was used without other fertilizer. Calcium cyanamide 12.0 gm. per square foot applied to soil 28 days before seeding gave fair control of onion smut, 10 percent as against 76 percent in untreated soil, but was injurious to onion seedlings.

Ammonium sulfate and hydrated lime used together are known to prevent damping-off (12) but, as used by the writer, they were ineffective against onion smut. Ammonium sulfate 10 gm. per square foot was applied, 28 days before seeding, to soil which had received hydrated lime 20 gm. per square foot earlier. This treatment did not at all control onion smut.

As Doran and Sproston (13) have reported, onion smut was well controlled by Fermate 58 pounds per acre applied to soil immediately before seeding. Fermate was used alone or, more often, in a carrier of fertilizer. Such use of fertilizer as a carrier did not lessen the fungicidal effects of the Arasan or Fermate which was added to it. With 88 percent smut in untreated soil and 56 percent smut with fertilizer only, there was only one percent smut in soil to which Fermate was applied in fertilizer.

In three instances, fertilizer, 1500 pounds per acre, was used alone, without fungicide, and the results as regards onion smut were compared with those in the same soils without fertilizer. In every case, there was less onion smut with fertilizer than without it, the percentages of smut dropping from 85 to 62 percent in one soil, from 88 to 56 percent in another, and from 47 to 25 percent in another.

Results of other experiments in which Fermate was used for the control of onion smut are summarized in Table 5. Fermate 0.5 to 1.0 gm. per square foot controlled smut well when applied to soil one, two, or ten days before seeding. Fermate in these amounts gave little or no protection against smut when applied to soil six weeks before seeding, which result may be in agreement with those of Townsend (39) who found indications that Fermate breaks down too soon to protect (celery) plants against damping-off for many weeks.

Onion smut was also well controlled by Arasan 0.5 or 0.6 gm., or Phygon 0.6 or 0.65 gm. per square foot. The effectiveness of Arasan and of Fermate in controlling smut was unaffected by the presence or absence of hydrated lime 20 gm. per square foot, applied previously in some cases.

Onion smut was not at all controlled by applications of hydroxylamine hydrochloride, benzidene dihydrochloride or phenylhydrazene hydrochloride 4.0 gm. per square foot in all cases.

The severity of the disease was lessened by Dow Seed Protectant No. 9, 0.4 gm., or Dow Seed Protectant No. 9B, 1.25 gm. per square foot, but these treatments sometimes retarded the growth of onion seedlings.

In the experiments the results of which are summarized in Table 5 both smut and damping-off were factors affecting the number of plants which survived from a given number of seeds.

TABLE 6.—EFFECTS OF SOIL FUNGICIDES ON STANDS AND GROWTH OF ONION SEEDLINGS IN THE ABSENCE OF ONION SMUT.

Soil Treatment per Square Foot	Relative Number of Plants Which Lived	Average Green Weight per Plant Expressed as Relative Numbers
SERIES A		
None	100	100
Fermate 0.7 gm.	333	195
Phygon 0.6 gm.	407	200
Tuads 0.65 gm.	440	200
SERIES B		
None	100	100
Arasan 0.7 gm.	201	114
Hydrated lime 20 gm.	129	108
Mercurous chloride 0.2 gm.	93	63
Mercurous chloride 0.2 gm. and hydrated lime 20 gm.	150	102
Phygon 0.7 gm.	240	129
SERIES C		
None	100	100
Phygon 0.55 gm.	143	175
Tuads 0.55 gm.	147	162
SERIES D		
None	100	100
Dithane D-14, 2.0 cc.	300	108
Dow Seed Protectant No. 9, 0.75 gm.	312	102
SERIES E		
None	100	100
Dow Seed Protectant No. 9, 0.45 gm.	187	105
Phygon 0.45 gm.	200	113
Tuads 0.6 gm.	179	144
SERIES F		
None	100	100
Dithane D-14, 2.5 cc.	113	132
Dow Seed Protectant No. 9, 0.4 gm.	144	164
Hydrated lime 20 gm.	109	100
Phygon 0.5 gm.	137	173
Phygon 0.5 gm. and hydrated lime 20 gm.	141	173
Tuads 0.5 gm.	124	110
Tuads 0.5 gm. and hydrated lime 20 gm.	127	137

In the experiments represented in Table 6, soil not infested with onion smut was used, so the final stands depended upon the control of damping-off and, as always, on possible injury to seed or seedling by the fungicide. The exact improvements in stands resulting from the same or a similar treatment varied here as elsewhere with the severity of damping-off in untreated soils.

As with cabbage, so with onion seedlings, mercurous chloride 0.2 gm. per square foot (see Series B) was more effective or safer when used with hydrated lime 20 gm. than when used alone. But the results with Arasan 0.7 gm. or Phygon 0.7 gm. per square foot were better than those with mercurous chloride.

In both limed and unlimed soil, Phygon 0.5 gm. and Tuads 0.5 gm. per square foot were effective in improving stands of onion seedlings (see Series F), but seedlings made better growth with Phygon than with Tuads.

In one case (Series D), Dithane D-14, 2.0 cc. per square foot, markedly increased the number of plants which lived; but in another (Series F), Dithane D-14, 2.5 cc. gave results inferior to those obtained with Dow Seed Protectant No. 9, 0.44 gm., Phygon 0.5 gm., or Tuads 0.5 gm. per square foot.

As may be seen by reference to Table 6, stands were improved and growth of onion seedlings was better in soils treated with all of the organic fungicides used and, as used, they were quite safe. The growth of the seedlings in untreated soil was probably retarded by fungi which cause damping-off.

It seems evident from all this that Fermate, Arasan, or Phygon when applied to soil in fertilizer may be expected to protect onion seedlings against both smut and damping-off.

The writer is informed and believes that about one-third of the onion seeds sowed in the Connecticut Valley in Massachusetts, including seeds sowed for the production of sets, are treated with Arasan or other form of tetramethyl thiuram disulfide, about one-third are protected by formaldehyde applied to the soil, and the remainder are sowed without any protective treatment of seed or soil.

Earlier investigators (18, 38) had good results with Arasan used for the treatment of onion seeds for the prevention of smut. Arasan, mixed in the drill at the rate of one pound of the fungicide to four pounds of seed, gave satisfactory control of onion smut in moderately infested soil; less satisfactory control in heavily infested soil (35). Arasan used for the treatment of onion seeds gave better control of damping-off than did Spergon, Semesan, or Fermate similarly used (40).

As used by the writer for the treatment of seeds of onion in the experiment reported in Table 7, Arasan gave better results than did Fermate in controlling both smut and damping-off.

There was no control of onion smut by zinc salicylate, bismuth salicylate, ammonium dichromate, or potassium dichromate used as seed treatments.

TABLE 7.—EFFECTS OF SEED TREATMENTS WITH ARASAN AND FERMATE ON ONION SMUT AND ON STANDS OF ONION SEEDLINGS.

Seed Treatment	Percentage of Seedlings with Smut	Percentage of Seedlings Which Lived
None	77.0	7.0
Fermate	33.3	43.1
Arasan	3.2	82.7

The Control of Damping-off of Seedlings of some other Vegetables by Fungicides Applied to Soil in Fertilizer

To determine how the effectiveness of certain fungicides in controlling damping-off is affected by the method of their application to soil, Dithane D-14, Dow Seed Protectant No. 9, and Tuads were applied to soil in fertilizer immediately before seeding or in water immediately after seeding. When the fungicides were applied in fertilizer, an equal volume of water was applied immediately after seeding, and all soils, untreated or however treated, received the same application of fertilizer. Results are recorded in Table 8.

Dow Seed Protectant No. 9, 0.6 gm. per square foot, gave better results with all species named in Table 8 when applied in fertilizer than when applied in water. In fertilizer, it increased the number of pepper seedlings which lived by 39 percent, but when applied in water it was without effect on the numbers surviving. Growth of onion seedlings was poorer when the fungicide was applied in water than when fertilizer was used as the carrier.

Stands of beet, cabbage, cucumber, and onion were more improved by Dow Seed Protectant No. 9, 0.45 gm. in fertilizer than in water, although the methods were equally effective with tomato. The percentages of cucumber seedlings

TABLE 8.—EFFECTS ON STANDS AND GROWTH OF SEEDLINGS OF FUNGICIDES APPLIED IN FERTILIZER AND IN WATER.

Soil Treatment per Square Foot	Relative Number of Plants Which Lived					Average Green Weight per Plant Expressed as Relative Numbers			
	Beet	Cabbage	Cucumber	Onion	Tomato	Beet	Cabbage	Cucumber	Onion
SERIES A									
None	100	100	100	100	100				100
Dow Seed Protectant No. 9									
0.6 gm. in water	212	83	234	38	191				42
0.6 gm. in fertilizer	2312	290	193	187	297				98
SERIES B									
None	100	100	100	100	100	100		100	
Dow Seed Protectant No. 9									
0.45 gm. in water	236	100	1350	244	127	67		112	
0.45 gm. in fertilizer	355	714	1552	763	127	189		117	
SERIES C									
None	100	100	100	100	100	100	100	100	100
Dithane D-14									
2.5 cc. in water	2744	204	123	256	220	115	90	100	108
2.5 cc. in fertilizer	2637	249	123	300	229	112	90	100	108
SERIES D									
None		100		100			100		100
Tuads									
0.55 gm. in water		94		250			123		128
0.55 gm. in fertilizer		94		1235			173		171

which damped-off were 60 percent in untreated soil, 32 percent with the fungicide in water and 3 percent with the fungicide in fertilizer. Growth of beet, cabbage, and tomato seedlings was more improved or less retarded when the fungicide was applied in fertilizer rather than in water.

Differences in stands of seedlings of all species named in Table 8, as well as of cress seedlings, were smaller or negligible in the case of Dithane D-14, 2.5 cc.; but seedlings of tomato made more growth when the fungicide was applied in fertilizer, not in water.

Tuads 0.55 gm. in fertilizer improved the stands and growth of onion and the growth of cabbage more than did this material in water. Percentages of onion seedlings which damped-off were 84.7 percent in untreated soil, 68.2 percent in soil treated with Tuads in water, 7.1 percent in soil treated with Tuads in fertilizer.

It should be remembered that when fungicides were applied dry, that is in fertilizer, the fungicide–fertilizer was thoroughly mixed with the soil to the depth of the container, or about four inches. It is possible that the usually somewhat inferior results obtained when the fungicides were applied in water were due to a less complete or even penetration of the soil by the fungicide when carried in water. In the work now to be described, all fungicides were applied to soil in fertilizer.

The numbers of pepper seedlings which lived were increased 53 percent by Phygon 0.45 gm. or by Tuads 0.45 gm. per square foot, less by Dow Seed Protectant No. 9, 0.45 gm. Pepper seedlings made the most growth, an increase of 32 percent in green weight, with Phygon.

The number of eggplant seedlings which lived was increased 20 percent by Phygon 0.5 gm. per square foot which was more than the increase resulting from the application of Dithane D-14, 2.5 cc., Dow Seed Protectant No. 9, 0.4 gm., or Tuads 0.5 gm. per square foot. Growth was unaffected.

Results with beet, cucumber, and tomato are summarized in Table 9. Growth was not retarded by any of the materials listed and the stand of seedlings was improved by Dithane D-14, 2.0 cc. or 2.5 cc.; Dow Seed Protectant No. 9, 0.4,

0.45, 0.55 or 0.6 gm.; Phygon 0.45, 0.5 or 0.55 gm.; MTD 0.7 gm.; or Tuads 0.45, 0.5 or 0.55 gm. per square foot.

But growth of cress seedlings was retarded by Dithane D-14, 2.0 cc. And Dow Seed Protectant No. 9, 0.75 gm. per square foot interfered with the growth of both cress and tomato.

TABLE 9.—EFFECTS OF FUNGICIDES APPLIED TO SOIL IN FERTILIZER ON STANDS OF BEET, CUCUMBER, AND TOMATO SEEDLINGS.

Soil Treatment per Square Foot	Relative Number of Plants Which Lived		
	Beet	Cucumber	Tomato
SERIES A			
None	100	100	100
Dithane D-14, 2.0 cc	452		215
Dow Seed Protectant No. 9, 0.6 gm	500	155	210
SERIES B			
None		100	100
Dow Seed Protectant No. 9, 0.55 gm		230	
Phygon 0.55 gm		244	346
Tuads 0.55 gm		244	381
SERIES C			
None	100	100	100
Dow Seed Protectant No. 9, 0.45 gm	353	556	
Phygon 0.45 gm	304	643	294
Tuads 0.45 gm	206	850	291
SERIES D			
None	100	100	100
Dow Seed Protectant No. 9, 0.45 gm	400	336	
Phygon 0.45 gm	438	208	134
Tuads 0.45 gm	263	325	145
SERIES E			
None	100	100	100
Dithane D-14, 2.5 cc	223	460	215
Dow Seed Protectant No. 9, 0.4 gm		823	
Phygon 0.5 gm		802	272
Tuads 0.5 gm	223	904	278
SERIES F			
None			100
Arasan 1.0 gm			247
MTD 0.7 gm			241
Phygon 0.7 gm			238

Chromates and Dichromates Used for the Treatment of Seeds

Although this bulletin deals principally with soil treatments, the following work with seed treatments is included because seed treatments such as are here described are in a sense soil treatments, the seed being the vehicle by means of which the fungicide reaches the soil immediately around the seed.

Chromates are known to be fungicidal and have been used as wood preservatives. McCallan (32) used two chromium compounds, $7ZnO.2HgO.2CrO_3.7H_2O$ and $ZnO.4CuO.CrO_3.HX_2O$, which showed promise as seed treatments in comparison with standard fungicides. But, probably because chromium compounds have been regarded as less than safe, little use has been made of them as fungicides on living plants.

The chromates and dichromates used for seed treatments by the writer were ground with mortar and pestle and, in most cases, mixed with graphite in the proportions of 1:1, 1:2, or 2:1 by weight. Effects on stands of seedlings are recorded in Table 10.

Potassium dichromate-graphite 1:1 retarded the growth of cabbage, cress, and lettuce but not beet, chard, cucumber, and tomato. Growth of seedlings of cress was also retarded by sodium chromate-graphite 2:1 and by sodium dichromate-graphite 1:1.

TABLE 10.—EFFECTS OF SEED TREATMENTS WITH CHROMATES AND DICHROMATES ON STANDS OF SEEDLINGS.

Seed Treatment	Relative Number of Plants Which Lived					
	Beet	Cabbage	Chard	Cress	Cucumber	Tomato
SERIES A						
None	100		100	100	100	
Potassium dichromate–graphite 1:1	609		1187	146	178	
Semesan	554		825	146	125	
SERIES B						
None	100	100		100	100	100
Potassium dichromate–graphite 1:1	214	107		224	300	92
Ammonium dichromate–graphite 1:1	143	89			425	133
Sodium dichromate–graphite 1:1	86	143		175	478	92
Sodium chromate–graphite 1:1	114			206		119
Semesan	117	139		253	400	94
SERIES C						
None	100				100	100
Ammonium dichromate–graphite 1:2					1434	385
Sodium dichromate–graphite 1:2	138				1173	374
Sodium chromate-graphite 1:2	169				1048	
Arasan	387				1445	
SERIES D						
None	100		100	100	100	
Potassium dichromate–graphite 1:1	464		315	167	148	
Sodium dichromate–graphite 1:1	68		123	167	138	
Semesan	475		423	211	117	
SERIES E						
None	100	100			100	
Potassium dichromate–graphite 1:1	391	124			572	
Semesan	373	153			514	
SERIES F						
None	100	100		100	100	100
Potassium dichromate	122	88		87	127	148
Potassium dichromate–graphite 2:1	129	100		109	100	230
Ammonium dichromate–graphite 2:1	106	129		80	104	219
Sodium dichromate–graphite 2:1	100	97		87	100	223
Sodium chromate–graphite 2:1	129	107		87	135	207
Semesan	100	104		106	119	200

The number of chicory seedlings which lived was increased 46 percent by potassium dichromate-graphite 1:1, 30 percent by Spergon or red cuprous oxide. Potassium dichromate-graphite 1:1 also gave good results with beet, chard, and cucumber but not tomato.

Potassium dichromate used alone, that is without graphite, as in Series F, apparently injured seeds of cabbage and cress but there were good stands of beet, cucumber, and tomato. Used alone, without dilution, ammonium dichromate, sodium chromate, and sodium dichromate all gave results inferior to those secured when these materials were mixed with graphite.

Ammonium dichromate-graphite 1:1 improved the stands of beet, cucumber, and tomato seedlings but apparently injured seeds of cabbage.

Sodium dichromate-graphite 1:1 gave poor results with beet and tomato, better stands of cabbage and cucumber, but did not give good control of damping-off of chard and cress.

Used in the proportion of one part of the salt to two parts of graphite, ammonium dichromate-graphite and sodium dichromate-graphite markedly improved the stands of cucumber and tomato seedlings. But Arasan used as a seed treatment gave better results than sodium dichromate-graphite 1:2 or sodium chromate-graphite 1:2 with beet.

Ammonium dichromate, sodium dichromate, or sodium chromate two parts with graphite one part apparently interfered with the germination of seeds of cress. But these materials and also potassium dichromate 2:1 gave good results with tomato. And potassium dichromate-graphite 2:1 or sodium chromate-graphite 2:1 improved the stands of beet seedlings.

Summarizing then, potassium dichromate-graphite 1:1 gave good results with beet, chard, and cucumber; ammonium dichromate-graphite 1:1 or 1:2 with cucumber and tomato, often improving stands in the order of the improvement obtained by the use of Semesan. But the chromates and dichromates were less safe for the treatment of the seeds of cabbage and cress, not infrequently causing injury to seeds or to seedlings.

The Control of Damping-off by a Delay in the First Watering after Seeding

Earlier investigators (1) found that damping-off caused by Pythium was severe in soil moist enough for good growth (moisture content, 45 percent of the water-holding capacity) and that the disease was checked only in what they considered a too dry soil (moisture content, 35 percent of the water-holding capacity). They concluded that damping-off is not controllable by the regulation of soil moisture. But they were more concerned with a relatively constant soil moisture content than with one which could be increased after some of the danger of damping-off, at least pre-emergence damping-off, had passed.

A first step in the germination of seeds is the absorption of water, and there does not need to be much water in the soil around the seeds for that to occur. Dry seeds of cowpea can take water from soil until the soil is practically air dry (43), and seeds of Xanthium, cocklebur, from soils so dry that plants cannot live in them (37). There was good germination of seeds of cucumber, radish, and tomato in a soil with a permanent wilting percentage of 14.9, and fair germination of seeds of endive when the soil moisture content was as low as 16 percent, or just above the permanent wilting percentage (9). This indicates that germination may take place or begin in a soil too dry for damping-off to be severe and suggests the use, where possible, of relatively dry soils for seeding.

It is known that stands of pea seedlings may be improved if several days are allowed to elapse between seeding and the first watering of soil thereafter. In a soil the moisture content of which was 55 to 65 percent of its water-holding capacity at the time of seeding, stands were better when the soil was first watered one or two days after seeding than when it was first watered immediately after seeding (26). In another case (25), the percentage emergence of pea seedlings from soil infested with damping-off organisms was much increased when the soil was first watered four days after seeding rather than a few hours after seeding. And progressively better stands of pea seedlings were obtained as the first watering of soil was postponed one, two, or three days after seeding (2). But the earlier investigators seem to have been more concerned with the relation of such findings to the effectiveness of seed treatments, or to weather in the field, than to the control of damping-off in greenhouses by the simple method which their results suggest; a method which, as will appear, deserves more emphasis than it has heretofore received.

In the work of the writer, soils, usually a mixture of one part sand and two parts sifted loam, were placed in flats and left unwatered in the greenhouse for a few days, losing moisture meanwhile, until the soil was in a condition which would ordinarily be regarded as too dry for the best growth of most seedlings. Seeds were then sowed, all as nearly as possible at the same time. The soil was watered for the first time, usually one quart of water per square foot, either immediately thereafter or one to several days later. These intervals are listed in Table 11, "0" days having reference to soil which was watered immediately after seeding. After the first watering, whether immediately after seeding or one or more days later, all seed flats were watered alike and at the same time.

In comparing stands (relative number of plants which lived from the same number of seeds), the basis of comparison is the number (raised to 100) which

survived in soil first watered immediately after seeding, this relationship constituting some measure of the effectiveness of a delay in first watering in controlling damping-off. The effect on post-emergence damping-off is expressed in terms of percentage of seedlings which damped-off after emergence. Since stands of seedlings were not usually improved by a delay of only one day between seeding and first watering, and were no more improved by a delay of seven days than by six, only delays of from two to six days are included in the table.

TABLE 11.—EFFECTS OF DELAYED WATERING ON STANDS AND POST-EMERGENCE DAMPING-OFF OF SEEDLINGS.

		Relative Number of Plants Which Lived						Percentage of Seedlings Which Damped-off after Emergence					
		Number of Days between Seeding and First Watering						Number of Days between Seeding and First Watering					
		0	2	3	4	5	6	0	2	3	4	5	6
Beet													
Series	A	100	380	460	920	1300	–	68	33	23	14	0	—
	B	100	447	267	393	–	527	15	5	5	0	0	3
	C	100	133	96	168	183	160	12	15	19	0	0	0
	D	100	147	161	208	200	–	31	16	5	0	0	—
Cabbage													
Series	B	100	510	497	617	–	494						
	C	100	356	443	400	294	375						
	G	100	386	533	–	–	638						
Cucumber													
Series	A	100	145	138	373	–	–	42	38	42	17	20	—
	B	100	512	215	356	–	451	60	27	46	30	49	—
	C	100	97	147	140	128	138	12	20	0	17	0	0
Eggplant													
Series	C	100	140	138	140	118	115						
	F	100	–	133	128	147	–						
Lettuce													
Series	A	100	232	253	245	–	–	29	17	19	20	—	—
	B	100	121	128	141	–	137						—
	C	100	833	833	1309	–	–	25	29	29	24	—	
	D	100	398	272	313	614	–	22	15	18	0	0	—
	E	100	–	–	143	–	150						
	F	100	–	133	139	136	–	10	—	3	0	3	—
Onion													
Series	F	100	–	168	185	144	–						
	G	100	408	536	–	–	633						
Pepper													
Series	F	100	–	136	129	135	–						
Tomato													
Series	A	100	123	115	131	146	–						
	B	100	92	88	130	–	139	11	4	11	0	—	8
	F	100	–	107	125	125	–						
	G	100	136	136	143	–	–						

The delay between seeding and first watering which was most effective in improving stands was usually three or four days with onion, lettuce, cabbage, and chicory; four or five days with beet and tomato; three, four, or five days with eggplant and pepper; three to six days with cucumber. The number of seedlings which lived was increased 28 percent by a delay of three days in the case of chicory; 35 percent by a delay of three or four days in the case of Chinese cabbage.

The improvement in stand following a delay of a few days in the first watering after seeding probably results more from some control of pre-emergence damping-off than from the control of post-emergence damping-off, although a delay in first watering often reduces the severity of post-emergence damping-off also. A comparison of the results shows that the improvement in stands due to a delay in first watering was often greater than the decrease in post-emergence damping-off.

Moreover, the number of plants which lived was often increased by a delay in the first watering after seeding even though there was no post-emergence damping-off in the soil which was first watered immediately after seeding or in soil first watered later. That was true of seedlings of tomato in Series A, F, and G; of cabbage in Series B, C, and G; of eggplant in Series C and F; and of lettuce in Series B and E.

TABLE 12.—EFFECTS OF DELAYED WATERING ON THE NUMBER OF DAYS BETWEEN SOWING OF SEEDS AND EMERGENCE OF SEEDLINGS.

Number of Days between Seeding and First Watering	Number of Days between Seeding and Emergence of Seedlings							
	Beet	Cabbage	Cauliflower	Chicory	Eggplant	Lettuce	Onion	Tomato
0	6	6	6	8	12	6	12	7
4	9	11	11	11	13	8	12	10
6	11	12	11	11	—	11	—	12
8	13	14	12	12	—	12	—	—

In Table 12 are recorded the number of days required for emergence of seedlings as affected by some delay in first watering of the soil after seeding. It appears from this that each day of delay in first watering was followed by a delay in emergence of seedlings of about 20 hours with beet, 26 hours with cabbage, 22 hours with cauliflower, 14 hours with chicory, and 17 hours with lettuce.

Seventeen days after seeding, green weights of seedlings of beet, cucumber, eggplant, lettuce, and tomato were slightly less when soil was first watered five days after seeding than when it was watered immediately after seeding; but a delay of four days did not affect weights of plants at that time. Twenty-two days after seeding, a delay of five days in first watering did not affect growth of seedlings; but seedlings sowed in soil first watered seven days after seeding still weighed slightly less than those in soil watered immediately after seeding.

Table 13 shows the effects of a delayed first watering on stands of beet and lettuce seedlings grown from untreated seeds and those grown from seeds treated with Arasan.

Stands of seedlings from treated seeds were good in all cases. When the intervals between seeding and first watering were three days or less in the case of beet, or four days or less in the case of lettuce, treated seeds resulted in better stands. But with a delay in first watering of four or five days for beet or five

TABLE 13.—EFFECTS OF SEED TREATMENT WITH ARASAN AND A DELAY IN FIRST WATERING ON STANDS OF PLANTS.

Number of Days between Seeding and First Watering	Relative Number of Plants Which Lived			
	Beet		Lettuce	
	From Untreated Seeds	From Treated Seeds	From Untreated Seeds	From Treated Seeds
0	100	203	100	497
2	147	192	398	614
3	161	203	272	657
4	208	184	313	543
5	200	184	614	618

days for lettuce, stands of plants were as good from untreated seeds as from treated seeds.

The benefits resulting from some delay in first watering are greatest when the disease-producing power of the soil—the danger of damping-off or what has been called the inoculum potential (25)—is great. They are least when the inoculum potential is so low that there is little or no damping-off in soil watered immediately after seeding. But that is true also as regards the control of damping-off by other means, the benefits usually being greatest when the need is most.

Stands are not likely to be much improved by a delay in first watering after seeding if the soil at the time of seeding is too moist. In the work of the writer, the benefits of delayed first watering were most apparent if the soil at the time of sowing seeds contained water to the extent of not more than 30 percent of its water-holding capacity. The soil should be dry enough not to adhere when compressed in the hand. Otherwise there is more likelihood of its being moist enough for some pre-emergence damping-off than of its being too dry for germination to begin. Four days after seeding, seedlings of broccoli began to emerge from an unwatered soil which contained moisture to the extent of only 30 percent of its water-holding capacity.

Summary

Fungicides were safely, effectively, and conveniently applied to soil in commercial fertilizer used as a carrier. The method resulted in better control of damping-off than was obtained when the fungicides used were applied to soil in water.

Clubroot of cabbage as it occurs on seedlings was usually well controlled by mercurous chloride 0.2 or 0.3 gm. (per square foot in all cases) added, in fertilizer, to soil which had received hydrated lime 20 or 25 gm. The disease was not usually well controlled by either mercurous chloride or hydrated lime used alone. The effectiveness of mercurous chloride against the disease was somewhat improved by the addition of sodium chloride to the soil, although much less than by similar use of hydrated lime. The effectiveness of mercurous chloride was lessened by the addition of sulfur to the soil.

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Mercurous chloride gave better results in the work on clubroot than did mercuric chloride.

Hydrated lime used alone lessened the severity of clubroot in a relatively dry soil but gave no protection against the disease in a more nearly saturated soil.

The degree of control of clubroot by mercurous chloride and hydrated lime was found to be affected by the moisture content of the soil. Thus this combination treatment of a soil in which, untreated, there was 100 percent clubroot, reduced the number of infected plants to 20 percent in soil 80 percent saturated, to 3.3 percent in soil 50 percent saturated.

Growth of cabbage seedlings was at first retarded by mercurous chloride; but later, the control of clubroot being a factor, plants made more growth in soil with mercurous chloride than in soil without it.

Mercurous chloride and hydrated lime controlled clubroot better than did the organic fungicides used. In the absence of clubroot, the number of cabbage seedlings which escaped damping-off was increased by Arasan or Phygon applied to the soil in fertilizer.

Onion smut was well and safely controlled by 2.75 gm. (per square foot) of sodium nitrite applied three days before seeding, or by 3.0 gm. of calcium or potassium nitrite ten days before seeding. Fermate, 0.5 to 1.0 gm. controlled onion smut well when applied to soil two or ten days before seeding. A 5-8-7 fertilizer

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used alone reduced the percentage of smut but not nearly so much as did the Fermate-fertilizer mixture. Onion smut and damping-off were also well controlled by Arasan 0.5 or 0.6 gm. When used for the treatment of seeds, Arasan gave better control of onion smut than did Fermate.

For the prevention of damping-off, Phygon applied to the soil in fertilizer gave good results with eggplant, pepper, beet, cucumber, and tomato. Stands of beet, cucumber, and tomato were also improved by Dithane D-14, Dow Seed Protectant No. 9, MTD, and Tuads similarly used.

Used for seed treatment, a potassium dichromate-graphite mixture or an ammonium dichromate-graphite mixture gave good results with beet, chard, cucumber, and tomato.

Loss by damping-off, especially the pre-emergence type, was less if soil at the time of seeding contained water to the extent of not more than 30 percent of its water-holding capacity, and if such soil was not watered until three to five days after seeding.

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